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Performance assessment of turbo-roundabouts in corridors

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Abstract

There is a widespread agreement in the scientific community that the transformation of a conventional multi-lane roundabout into a turbo-roundabout results in a significant increase of road safety levels. However there is no consensus regarding its effect in terms of capacity, as there are some authors that point towards a small reduction in capacity, namely in the major roads entries. The concept of turbo-roundabout is quite recent and therefore there are only a few studies of its performance, in particular, when applied in a network or in a corridor.

In this context, this paper focuses on the evaluation of the performance of the turbo-roundabout solution, when applied in corridor, compared to a normal double-lane roundabout. The analysis was based on two key components: capacity and pollutant emissions. The work was supported by microsimulation techniques using the AIMSUN software, based on a real case study calibrated and validated for this purpose.

It was possible to conclude that the turbo-roundabout performance is strongly influenced by the traffic load of the network, severely losing its performance in oversaturation conditions. The performance of the solution was also particularly sensitive to the traffic directional distribution, both in the entries as well as in the corridor. In global terms, it was found that the results for the environmental indicators follow the progress of the capacity indicators.

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1. Introduction

Roundabouts are internationally recognized for being solutions that ensure high levels of fluidity, capacity and road safety (FHWA, 2000; Brilon, 2011), and usually they are credited for having advantages in terms of pollutant emissions. When compared to other conventional at-level solutions, turbo-roundabouts are usually associated to a simple operation and as being easily understandable by drivers. This type of solution provides high performance levels, which is reflected in a reduction of road accidents that, depending on the geometric characteristics and country considered, can reach a 70% reduction of accidents frequency and a reduction above 90% in the number of fatalities (FHWA, 2000; Brown, 1995; Bastos Silva et al, 2011). The improvement on the safety levels compared to priority junctions is mostly due to the reduction of conflict points (from 32 to only 8) and homogenization of the speeds profiles resulting in a significant reduction in both the frequency and severity of collisions.

In terms of capacity, a single-lane roundabout can provide a geometric capacity close to 1200 veh./h. However, the need to accommodate high traffic levels has been justifying the use of multi-lane solutions to ensure higher capacity levels. Despite multi-lane roundabouts ensuring a good level of global performance, these solutions are usually associated with some of safety issues mainly caused by erratic driving behaviors which result in weaving maneuvers both in the entries and in the circulatory carriageway, as well as a tendency to invade adjacent lanes (Bastos Silva et al., 2004). These practices tend to generate a large number of conflicts, often resulting in accidents, although generally with low severity.

This type of problems has been worrying the technical and scientific community, as over the last two decades several alternative solutions have been tested without success, of which can be highlighted the innovative solutions in terms of road markings implemented in Australia (Austroads, 1993 and England (DfT, 2007). The turbo-roundabout started in the Netherlands, in the late XX century, as an alternative solution to conventional multi-lane roundabouts, introducing continuous spiral circuits in the circulatory carriageway, physically delineated by raised kerbs meant to prevent weaving movements trough lane changing and to induce low crossing speeds, by imposing higher deflection levels. The Dutch experience showed significant advantages of this solution over conventional double-lane roundabouts, in particular with a significant increase in road safety levels (Fortuijn, 2009a).

The success of this new solution has attracted the interest of the scientific community, which has motivated the development of scientific studies concerning the real performance provided by these solutions. Although there is a general consensus about the improvements to road safety, the same is not true in terms of capacity, as there are authors who point to a general increase in capacity, while others contest these results. In turn, the studies about pollutant emissions are still extremely scarce (Vasconcelos et al., 2014) as there are no general conclusions about its true impact in terms of local and global pollutants. Therefore the development of further research is justified so that it can contribute for a better understanding of the real performance of turbo-roundabouts, based on different levels of demand and traffic distribution.

2. State of the art

Several authors have shown that the transformation of a double-lane roundabout into a turbo-roundabout results in increased performance in terms of road safety. These benefits are usually associated with a reduction in the number of conflict points due to the placement of physical kerbs which prevent lane changing on entries, circulatory carriageway and exits (Bastos Silva et al, 2011; Fortuijn, 2009a, 009b; Giuffrè et al, 2009; Corriere and Guerrieri, 2012) and thus eliminate the weaving conflicts. In addition, the application of raised lane dividers prevents the practice of straight trajectories by imposing deflection levels that ensure the adoption of safer speeds.

According to Fortuijn (2009a), based "before-after" type studies, the transformation of conventional at-level intersections (priority intersections, multi-lane roundabouts) into turbo-roundabouts results in a reduction of about 70% of the accidents frequency, reaching safety levels similar to a single-lane roundabout. These results are consistent with those presented by SWOV (2007). Mauro and Cattani (2010), based on conflict analysis technics, point to lower values. The transformation of a conventional two-lane roundabout into a turbo-roundabout resulted in a reduction of the frequency of potential accidents between 40 and 50%, as there is a positive linear correlation between the potential number of accidents and the traffic volume. Also Vasconcelos et al. (2014) found benefits in terms of safety. Using microsimulation techniques and SSAM software (Surrogate Safety Assessment Model), a

comparative performance analyzes between single-lane roundabouts, multi-lane roundabouts and turbo-roundabouts was developed. The results show that the turbo-roundabout is the best of the three solutions evaluated, tending to have a lower number of conflicts than the single-lane roundabout, although more severe.

Also in terms of capacity there are some scientific studies, although their results are not always consensual. Yperman and Immers (2003), using microsimulation techniques, obtained capacity increases between 12 and 20% when turning a conventional roundabout into a turbo-roundabout, both with three circulatory lanes, with the performance depending on the traffic distribution adopted. Engelsman and Uken (2007), on the other hand, used the “quick-scan” model, which is a strategic macro model developed by the province of South Holland, and estimated capacity gains for the turbo roundabouts of between 25 and 35%. Fortuijn (2011), using the Haging formula (Haging, 1998), concluded that the capacity of turbo-roundabouts is generally higher than on conventional roundabouts. Mauro and Branco (2010), based on the gap acceptance theory and different scenarios of traffic distribution concluded that for balanced traffic distributions the turbo-roundabout tends to ensure a higher overall capacity when compared to conventional roundabouts, both in saturated and unsaturated conditions. Nevertheless, they state that at the main entries, the turbo-roundabouts’ capacity is always lower than in a conventional roundabout. However it should be noted that the turbo-roundabouts’ operation is different from the conventional roundabout, as the capacity prediction models in conventional roundabouts are not directly applicable to this new solution, and so a differentiated analysis for each traffic lane is recommended (Giuffrè et al, 2009).

In recent studies carried out by Vasconcelos et al. (2012, 2014), the main differences affecting the capacity estimates, and based on the Haging formula are shown and it was concluded: (i) the capacity of the major road entries of turbo-roundabouts are always lower than the conventional roundabouts because the opposite traffic flow is only concentrated in one lane of the circulatory carriageway; (ii) the relative performance of turbo-roundabouts decreases with increasing demand in the main direction, reaching capacity losses of 40%; (iii) in secondary entries, turbo-roundabouts ensure better performance, but only for specific demand scenarios, especially with very high proportion of right turns (above 60%). These results show the importance of the analysis, as the performance of the turbo-roundabout undeniably depends on the traffic volume and on the traffic distribution.

In terms of pollutant emissions the number of studies is still scarce and the results are highly dependent on the roundabouts’ performance in terms of fluidity and capacity and therefore not consensual. Vasconcelos et al. (2014) is one of the few studies, and it is based on a real case study operating under saturation level. The pollutants (CO₂, CO, NO_x and HC) were estimated using the VSP model (Vehicle Specific Power), which estimates, in a dynamic way, emissions, based on the speed and acceleration of vehicles and the road slope, using data exported from the microsimulation software AIMSUN. The results showed that the emissions of CO₂ and NO_x are higher in turbo-roundabouts compared to conventional double-lane roundabouts. However, for CO and HC a turbo-roundabout is presented as the best solution.

3. Objectives and general methodology approach

The state of the art review shows that the evaluation of the turbo-roundabouts’ performance is not yet consolidated, particularly in the field of capacity and pollutant emissions, as the results depend on the methodology adopted, as well as the traffic demand and distribution considered. On the other hand, the studies that were found are mainly focused on the assessment of the performance of individual solutions and it is not common to find reference to studies broaching its application in a corridor or network. The research work carried out by Iowa State University (Isebrands, H., et al., 2008) is one of the few that considers land use, access management and other planning issues. The results show that the integrated use of roundabouts may not have the same benefits that are assumed for an isolated roundabout. However, this study was based on only two corridors with traffic lights, and so it is important to analyze other solutions and layout combinations.

In this context, the general objective of this work is focused on the evaluation of the performance of turbo-roundabouts at two fundamental levels: (i) capacity; (ii) pollutant emissions. The study was based on a real example with a succession of 3 intersections of the arterial road network of the city of Coimbra, Portugal that can be transformed into turbo-roundabout solutions.

The work developed was based on a comparative analysis of the performance of solutions corresponding to two possible scenarios: (1) existing solution composed by conventional roundabouts with a double-lane circulation

carriageway; and (2) alternative solution with the conventional roundabouts transformed into turbo-roundabouts.

The most recurrently approaches used to evaluate the performance of alternative solutions are the "before and after" methods. However these methods require the physical implementation of these solutions which prevents the development of this type of work in countries where turbo-roundabouts do not exist. As the objective is to develop a comparative analysis microsimulation technics were employed. The software used was AIMSUN software (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks).

Similarly to previous studies (Vasconcelos et al., 2014) a limited set of performance indicators were selected in order to characterize the corridors' operation, in terms of capacity: Queues (number of vehicles) and Travel time (s/veh.). At an environmental level the global indicators used were provided by AIMSUN. These are representative of the greenhouse gas effect (CO₂), local pollutants (HC, CO and NO_x), energy efficiency (fuel consumption) and indicators that represent the harmful impact on the populations' health (PM – Particulate Matter). In terms of methodology the following indicators were considered: (i) Total Kg of CO, HC and NO_x emissions on the network, resulting from the QUARTET model and (ii) CO₂ and PM emissions per vehicle in g/Km, resulting from the application of the Panis et al. model (TSS, 2012).

4. Development of the simulation model

The development of the simulation model had three key stages: (1) model construction; (2) calibration and (3) validation of the model.

The O/D matrix was built based on extended data collection sessions in key sections of the network. These sessions included the collection of directional splits in all entries of the 3 roundabouts, complemented by a set of additional control counts. These counts characterized a normal day of the local network. The morning peak period was chosen [7:30 AM. - 9:30 AM] as it is considered to be critical for the city of Coimbra. These counts were segregated in 15 minutes periods and by vehicle type, in order to include the demand variation in the simulation by vehicle type, in the whole simulation period. Table 1 presents the global flows obtained for the road network. The peak demand was between 8:15 and 8:30 AM, with about 4400 veh/h entering the network.

Table 1. Global flows discharged in the network (veh/15 minutes)

Time period	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15
Light vehicles	415	555	700	1058	957	877	884	697
Heavy vehicles	17	19	17	19	16	19	15	15

Two simulation models were developed: (i) current solution as the reference solution; (ii) alternative solution of turbo-roundabouts with similar space requirements. The current network consists of 3 large roundabouts with two lanes in the circulating carriageway, with an outer diameter ranging from 55 m to 60 m. The distance between the roundabouts is about 400 and 470 m, respectively, between roundabouts A and B, and B and C. The major road has 2 carriageways and 2 lanes on each direction with 3.5 m wide each (Figure 1). The secondary roads mostly have one lane on each direction. In addition to the stretches between the 3 roundabouts, the study covered two more connecting stretches to other two roundabouts from the major road, making a total length of about 1760 m.

In the turbo-roundabouts model the layout type was selected according with the importance of the directional movements involved. Therefore the "standard" layout was assigned for the intersections A and B while roundabout C was transformed into a "knee" turbo-roundabout, with segregation of one of the right turning maneuvers (corresponding to the actual situation).

As the objective of this study is a comparative analysis of scenarios the calibration process was not very relevant, since what was assessed were the improvements/worsening compared to a reference scenario. As a consequence it only the calibration parameters *speed acceptance* and *time reaction* were adjusted. The *acceptance speed* (SA, vehicle parameter measuring the driver's degree of compliance of the speed limits on the section) was adjusted based on free flow speed profiles recorded using an instrumented vehicle in both directions of the circuit. These profiles were used to get the distribution of instantaneous speeds in sections where they reached a steady speed between turbo-roundabouts, having been adopted the following distribution of values ($SA_{av} = 0.98$; $SA_{min} = 0.78$; $SA_{max} = 1.26$; $\sigma = 0.09$). Simultaneously, the value of the average *time reaction* was adjusted until it was possible to

obtain queue lengths similar to those observed locally, on the various entries of roundabouts. The value of 0.8 s was adopted (as the default value is 0.75 s).

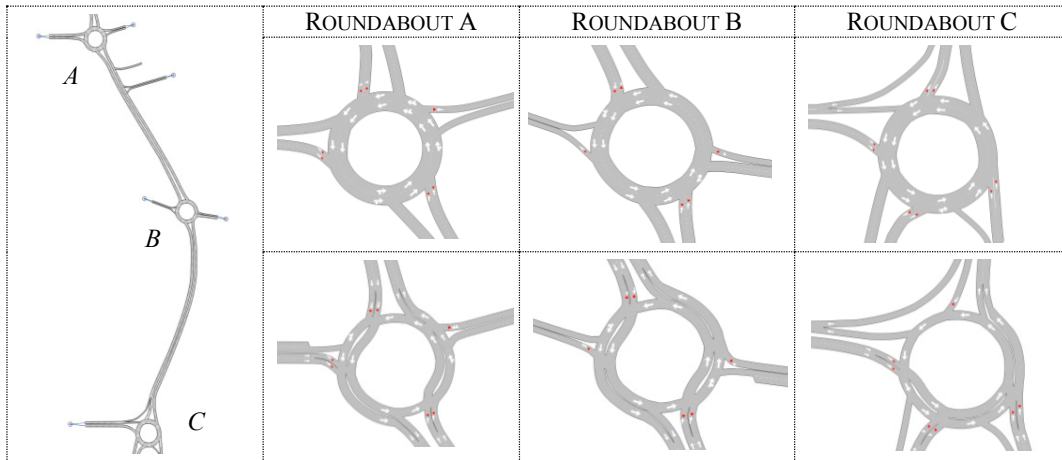


Figure 1. Network codification: (up) *actual solution (conventional roundabouts)*; (down) *turbo-roundabouts model*

In turn, the model validation focused on comparing the mean travel time between different O/D pairs, for an independent database, based on the real data, collected by O/D license plate registration, under free-flow conditions. Generally, the simulated values exceeded in about 12% the measured values from O/D pairs, at the location zone. The application of a t-student test confirms the existence of significant differences between some pair values (about 30%), however, and given the main objective of this study, the level of requirement of the degree of adjustment was reduced thus assuming the model as validated.

5. Definition of scenarios

As in previous studies (Vasconcelos et al, 2014) two types of scenarios were defined: (1) increased global demand for network traffic and, (2) variation of the directional distribution of traffic at the roundabouts' entrances. In the first analysis, the performance of the solutions was evaluated when subjected to increments of 10% in the total traffic demand while maintaining the observed directional distribution. The baseline situation (100%) correspondent to the demand within the network, to which multiplicative factors of between 0.6 and 1.3 were applied, comprising scenarios of under and over saturation. Based on Hagrings generic capacity formula (Hagrings, 1998) that describes the complex interactions between the different traffic streams of multilane roundabouts, and using parameters calibrated for the Portuguese conditions (statistical distribution of headways, critical gaps, follow-up time - see Vasconcelos et al., 2012_a) it was realized that the network is operating near the saturation threshold, with entries A3 and B3 reaching saturation levels of 90%.

The second analysis aimed at the creation of scenarios where the directional distribution of inputs was changed, imposing 25% increments while keeping constant the entrance traffic flow values. Two different situations were considered reaching a total of 27 combinations (C1 to C27): (i) the imposition of the same variation of the directional distribution in 3 roundabouts and various inputs (Scenarios C1 to C15), (ii) impose a directional distribution in the central roundabout (B) opposite to the extreme roundabouts (Scenarios C16 to C27) (example: when increasing the proportion of right turns at roundabouts A and C, the percentage of turns left at the roundabout B increases) – see table associated to Figure 6. Since the results tend to differ between successive replications due to the traffic stochastic phenomena, the result of each scenario was considered as the average of 10 replications in order to estimate the mean with a certain level of confidence without a significant computational effort. This number of runs assures the desired range (as desired confidence interval divided by standard deviation) as 2.0 at a 95- percent confidence level (FHWA, 2004).

6. Analysis of the results

6.1. Performance evaluation of the Turbo roundabout corridor – the effect of the traffic load level

Figure 2 shows extremely interesting results. It is clear that there are significant differences between the overall performance level provided by the conventional roundabouts corridor and the turbo-roundabouts, depending on the network load level. In terms of capacity the performance of the conventional roundabouts tends to be superior to the turbo-roundabouts, in particular with high demand levels. A significant worsening of the various performance indicators was also noticeable in operating conditions above saturation levels. It is expected that for the current traffic demand levels (100%) the construction of a turbo-roundabout corridor in saturated conditions could work, although a conventional roundabout solution would maintain a slight capacity reserve.

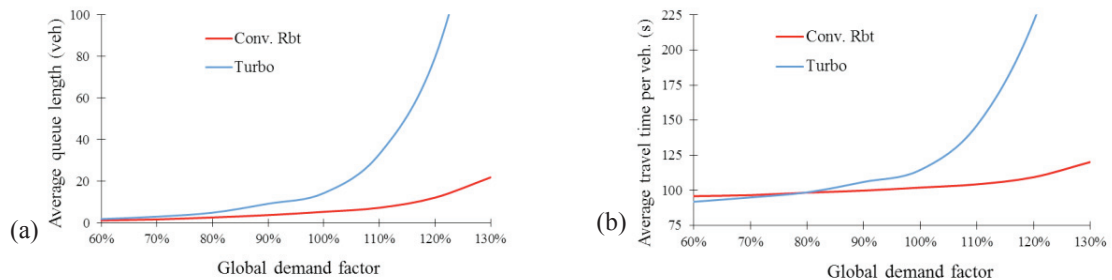


Figure 2. Variation of operational indicators with increasing traffic load on the network: (a) queue length; (b) average travel time

Only for unsaturated conditions (load less than 70%), the turbo-roundabouts corridor has a similar performance level or even slightly higher to the conventional roundabouts corridor. This benefit, though minor, tends to increase with lower traffic levels on the network (load of less than 70%). In terms of queues, traditional roundabouts always have better results, as already shown by the results previously obtained by Vasconcelos et al. (2014).

In terms of fuel consumption (Figure 3_a), the progress of the curves is similar to the travel time, and for load levels above 100%, the increase in consumption in turbo roundabouts is substantially higher than that of traditional roundabouts, reflecting the poor network operation. For a 130% load level, the increase in consumption is 45%, reaching levels comparable with a network load level close to 90%.

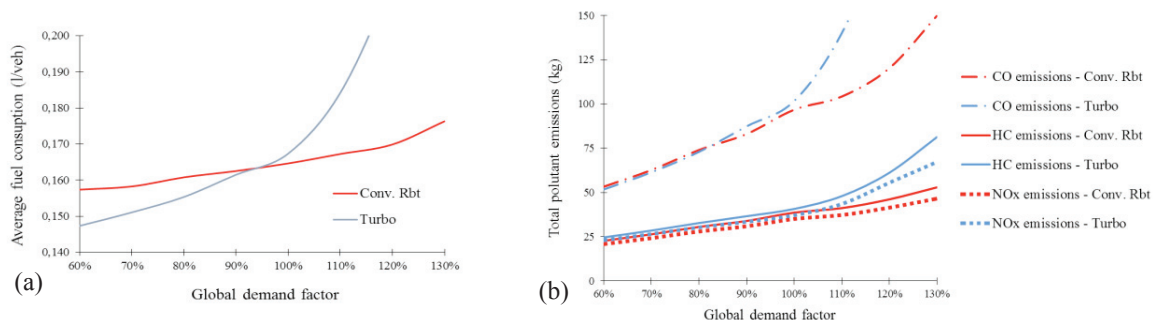


Figure 3. Emissions indicators taking into account the traffic demand load: (a) Fuel consumption; (b) total pollutant emissions

The same conclusions can be drawn with regard to CO, HC and NOx (Figure 3_b). The loss of performance is particularly significant in terms of CO, with an increase of 91% for a 130% demand load on the road network compared to traditional roundabouts. Also HC and NOx pollutants follow this trend, with increases of 54% and 44%, respectively. However this difference is diminished for demand levels lower than 100%, which show a balance between the performances of the two types of solutions. For load levels below 80%, it is even noticeable that turbo-roundabouts have better CO performance when compared with conventional roundabouts.

Also in terms of global CO₂ emissions and PM (Figure 4_a and b), the results consistently point to a better performance of the roundabout corridor, and the performance loss of the alternative solution with the increasing of the traffic on the network. Yet for low traffic demand scenarios (60 and 70%), turbo-roundabouts are slightly more effective, although they suffer a marked reduction in performance for traffic levels above 80%.

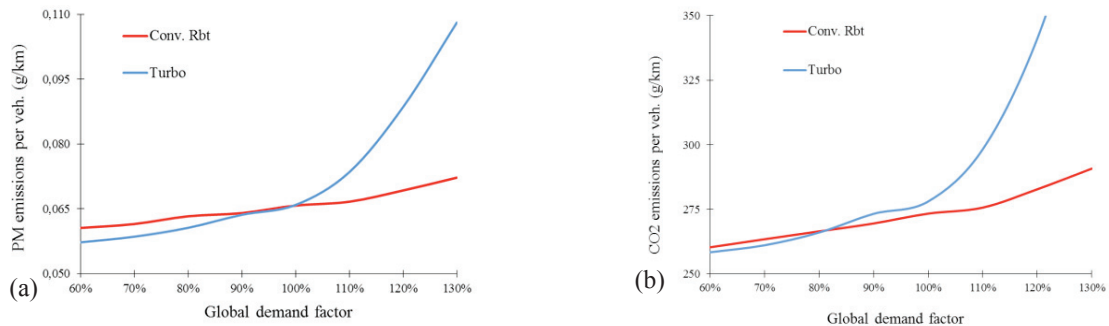


Figure 4. Emissions according to the traffic demand: (a) PM emissions; (b) CO₂ emissions

The results show that the turbo-roundabouts tend to have a steeper drop in performance when compared to conventional roundabouts, after the saturation threshold.

6.2. Performance evaluation of the Turbo-roundabout corridor – the effect of the traffic demand directional distribution

In a first phase, the effects of the directional distribution was evaluated keeping a constant traffic variation pattern in three consecutive roundabouts (C1 to C15 scenarios), based on the current level demand. The results show that conventional roundabouts are generally performing better than the turbo-roundabouts (Figure 5). The only exception corresponds to the scenario of 100% right turns and indicator of travel time, which is slightly lower in turbo-roundabouts. Therefore in this particular scenario the performance of the two solutions tends to be similar.

Thus, it can be concluded that, compared to conventional roundabouts turbo-roundabouts tend to have similar performance levels when the number of right turns is high, particularly when the proportion is equal to or greater than 50%. In contrast, when the ratio of left turns increases, the performance of the two solutions is significantly affected, but with a higher performance degradation in turbo-roundabouts.

Analysing the scenarios with a large percentage of forward movements it appears that, despite the layouts adopted for the turbo-roundabouts A and B favouring straight ahead movements, the conventional roundabouts ensuring a superior level of performance. A detailed analysis of the simulation showed that the recorded performance difference was due mainly to the roundabout C, whose turbo-roundabout layout type chosen "knee" although benefits right turns is clearly less effective in addressing the forward movements.

In a second phase, the effect of the directional distribution was evaluated when a pattern of differenced directional distribution variation was imposed in the roundabout B (scenarios C16 to C27). Interestingly the results follow the same trend of the results of previous analyses. In all scenarios considered, the corridor of conventional roundabouts has outperformed the turbo-roundabouts. It is however clear that for higher percentages of right turns turbo-roundabouts tend to perform better. The scenario corresponding to 100% of right turns in roundabouts A and C and 100% left turns at roundabout B is the best for turbo-roundabouts achieving performance levels similar to those of traditional roundabouts.

For example Figure 6 shows the variation of the delay (similar to the travel time indicator) for the two models in comparison. Their analysis shows a trend of increasing delays or travel times as the percentage of forward movements' increases. There is also a clear tendency of increasing delays as the left turns percentage increases although this effect is not so apparent for high levels of forward movement. It is also worth mentioning that the scenario, corresponding to 100% of left turns at roundabouts A and C and 100% right turns in B (C19) is the one that has the worst performance for turbo-roundabouts.

The table associated with the Figure 6 also shows the relationship between the travel times of these two types of scenarios (for example ratio of C16 and C1) as applied to the roundabout corridor and turbo-roundabout. Therefore the turbo-roundabouts corridor is much more sensitive to directional variation than the double-lane roundabout corridor. The greatest reduction in travel times is obtained in scenario C23, when 75% of the left turns (all intersections) were replaced by 75% of right turns in the central turbo-roundabout, while maintaining 25% for forward movements. The reduction in travel times reaches 60%.

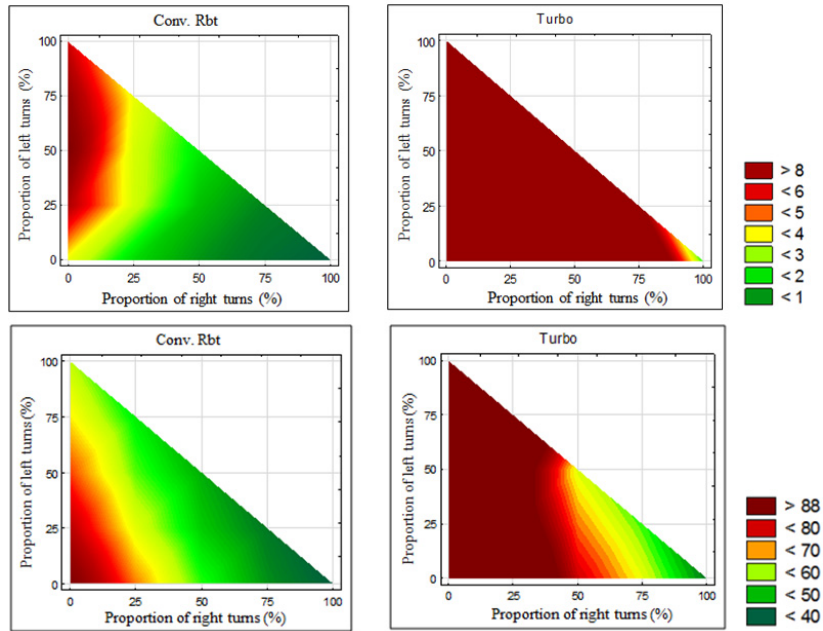
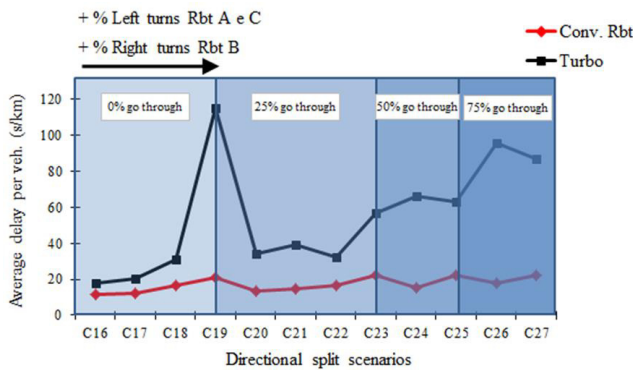


Figure 5. Effect of the directional distribution in the operating performance of roundabouts and turbo-roundabouts: (a) queues length (veh.); (b) average travel times (s/veh.)



Scenario (Ci and Cii)	Rbt A and C (and Rbt B for scenarios C1 to C15)			Rbt B (scenarios C16 to C27)			Travel time Ratio (relation between Ci/Cii)	
	←	↑	→	←	↑	→	Round	Turbo
C16/C1	0	0	100	100	0	0	1.1	1.2
C17/C2	25	0	75	75	0	25	1.0	1.0
C18/C4	75	0	25	25	0	75	1.0	0.7
C19/C5	100	0	0	0	0	100	1.0	0.6
C20/C6	0	25	75	75	25	0	1.1	1.1
C21/C7	25	25	50	50	25	25	1.0	1.1
C22/C8	50	25	25	25	25	50	1.0	0.8
C23/C9	75	25	0	0	25	75	0.9	0.4
C24/C10	0	50	50	50	50	0	1.1	1.3
C25/C12	50	50	0	0	50	50	0.9	0.5
C26/C13	0	75	25	25	75	0	1.0	1.0
C27/C14	25	75	0	0	75	25	1.0	0.8
C3	50	0	50	---	---	---	---	---
C11	25	50	25	---	---	---	---	---
C15	0	100	0	---	---	---	---	---

Figure 6. Effect of the directional distribution in the performance indicators at roundabouts and turbo-roundabouts

The same analysis applied to environmental emissions shows similar conclusions. The performance levels of the two alternatives in terms of consumption levels (Figure 7) tend to be closer in the scenarios corresponding to high percentages of right turns (equal or more than 50%). However, for the remaining scenarios, the conventional roundabout corridor tends to ensure a better level of performance. In the scenarios with the highest percentage of left

turns, the level of consumption in the turbo-roundabout solution tends to surpass significantly (by 90%) the conventional roundabout solution.

The assessment of these scenarios in terms of emissions of pollutants CO, HC, NO_x, CO₂ and PM, also points towards a better performance of the conventional roundabouts. For the pollutants CO, HC and NO_x, generally the solution of conventional roundabouts is always favourable. However, the results show a better balance between performance of the two solutions when the percentage of right turns is significant (equal or more than 50%), and accordingly, the emissions increase in turbo-roundabouts is less than 30% for CO and less than 20% for HC and NO_x. For CO₂ and PM the performance of the two alternatives is close in most scenarios, although the roundabouts corridor is slightly best. The average emissions increase by about 15% with the transformation into turbo-roundabouts, except for the scenarios associated with a high percentage of left turns, where the emission increases were very significant.

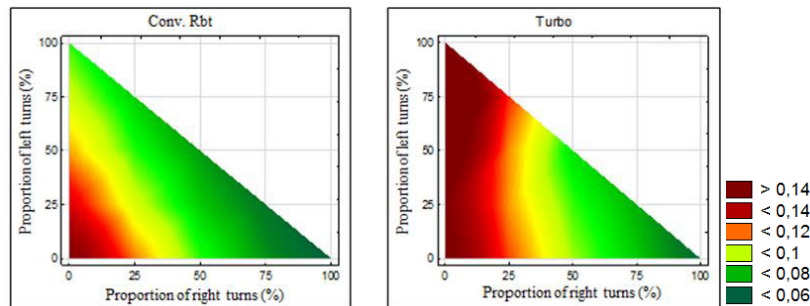


Figure 7. Effect of the directional distribution in fuel consumption for roundabouts/turbo-roundabouts

7. Main conclusions

This papers' main goal was to evaluate the performance of a turbo-roundabouts corridor in terms of capacity and environmental efficiency.

The results obtained tend to show that the level of performance of the turbo-roundabouts corridor is lower than that of conventional roundabouts, particularly near saturated traffic conditions. The turbo-roundabout corridor reached the saturation threshold for loads of 90% while the conventional roundabout corridor, could maintain loading levels of 110/120%. The results show that turbo-roundabouts tend to have a steeper degradation of performance than conventional roundabouts, after reaching the saturation threshold.

Nevertheless it has been found that this tendency is reversed if the traffic levels are low. For load levels below 70% the turbo-roundabouts proved to be able to ensure higher capacities. For loads of 80%, both solutions had similar performance levels (with the exception of fuel consumption that remained lower in turbo-roundabouts), and for loads greater than 90%, the corridor of conventional roundabouts outperformed the turbo-roundabout solution.

After analysing the effect of directional split it was found that only in scenarios with high percentage of right turns (more than 50%) there was an approximation of the performance levels associated with the two alternatives. The imposition of different combinations of directional distributions has validated these overall results.

In terms of emissions, it was clear that under reduced demand conditions, turbo-roundabouts lead to potential reduction of CO, CO₂ and PM. These reductions increase for high percentages of right turns. Moreover, the results showed that the turbo-roundabouts tend to increase the HC and NO_x emissions compared to conventional roundabouts, regardless of the level of demand.

These results are generally in accordance with the results of previous studies, applied to an isolated turbo-roundabout both in terms of overall capacity, the influence of the traffic distribution, as well as in terms of pollutant emissions. Nevertheless, it was found that its application in a corridor tends to be more sensitive to the directional distribution in the roundabouts sequence, reaching very sharp variations of the level of performance according to the various combinations of directional distribution studied. However the effect associated with the corridor should be analysed incorporating the effect associated with the distance between turbo-roundabouts.

Although this study mainly points to an advantage of conventional roundabouts compared to a turbo-roundabout corridor, it is important to acknowledge that the road safety analysis was not considered. Therefore the selection of the best layout for each particular situation should include a full and comprehensive analysis that cannot neglect this fundamental aspect that is usually an advantage of the turbo-roundabouts solutions.

Finally, the results also confirm the main domain of application of turbo-roundabouts. Regardless of being applied isolated or sequentially their application is particularly suited to suburban areas subject to moderate levels of traffic ensuring a working level below the saturation threshold.

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